ATES: WATER TREATMENT AND ENVIRONMENTAL IMPACTS

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ABSTRACT

In 1987, eight IEA countries started a new R&D task, Annex VI to the Implementing Agreement Energy Storage. The objectives of this task were to:
* systematically analyze the chemical, microbiological and environmental aspects of ATES, and subsequently;
* develop reliable, environmentally sound water treatment methods.

The principal findings from this R&D task are summarized in this paper.

1. INTRODUCTION

1.1 Historical background Annex VI

Annex VI to the IEA Implementing Agreement Energy Storage came into force on February 1, 1987. At that time the aquifer heat storage project SPEOS at Dorigny (Switzerland) had been operational for five years. This project had been included as a pilot project in the framework of Annex III to the same Implementing Agreement. Similarly, the exchange of information concerning pilot projects in Denmark (Hørsholm project) and the United States of America (St. Paul field test facility) were also part of Annex III.

Experience so far with these and other aquifer thermal energy storage projects had shown clearly that precipitation of chemical substances was the principal technical problem. The reliability of the applied water treatment methods was also questionable because of the lack of information on slow underground chemical reactions and the possible interactions between microbiological and chemical processes. Addition of hydrochloric acid, as applied at the SPEOS project for instance, seemed to be an effective water treatment method to prevent calcite precipitation. But this method can have adverse effects on groundwater quality. The resultant environmental impact could present a serious obstruction to the implementation of larger scale aquifer thermal energy storage projects.

Because the storage of thermal energy in aquifers is both technically and economically feasible, high priority must be attached to improving the reliability of the storage system by solving such (bio)geochemical and environmental problems. Therefore, eight countries decided to broaden the scope of the activities within the Implementing Agreement Energy Storage to the systematic investigation of the chemical, microbiological, and environmental impacts of aquifer thermal energy storage, and subsequently to the development of reliable, environmentally sound water treatment methods. With this, Annex VI entitled "Environmental and Chemical Aspects of Thermal Energy Storage in Aquifers and Research and Development of Water Treatment Methods" was a reality.

1.2 Annex VI

The storage of heat in an aquifer causes underground changes in temperature and flow of the groundwater (including the chemical substances and micro-organisms). The distribution of groundwater and heat in the soil did not form part of the research within the framework of Annex VI. Sufficient information is already available from other research in these areas.

Annex VI has been subdivided into two phases. The objectives of phase 1, which started in 1987 and had a duration of about four years, were to:

* analyze (both by modelling and experiments) the chemical, microbiological, corrosion and environmental aspects of ATES;
* evaluate different water treatment methods for heat storage, including both existing techniques and new concepts.

The components of phase 2 took place from 1991 to the end of 1993. The objectives of this phase were to:

* test, both in the laboratory and in the field, the most promising water treatment techniques, selected during phase 1;
* develop generically applicable procedures for the choice of the water treatment method to be used at a future ATES site and to assess the environmental impacts of the project.

The connection between the different facets of Annex VI is given in the following outline.

The principal results of phase 1 of the Annex VI research were published in 1991 (Snijders, 1991). This article mainly deals with the results of phase 2: the development and testing of environment-friendly water treatment techniques for ATES.

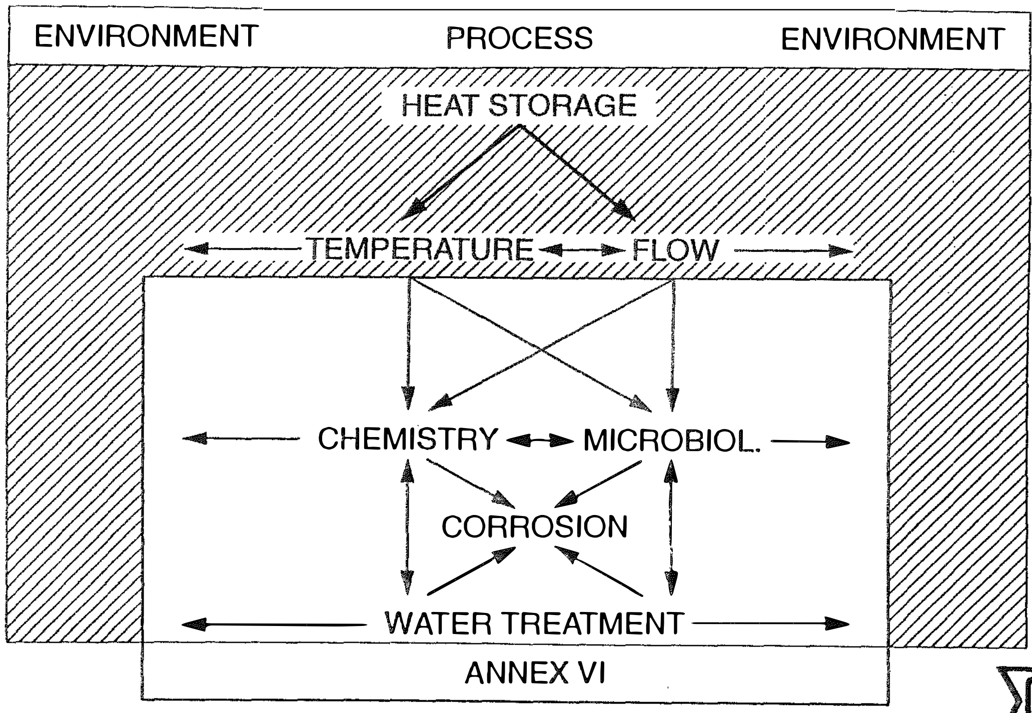

Figure 1 Scope of the Annex VI research.

2. PRINCIPAL RESULTS PHASE 1

2.1 Geochemical-transport model

An important part of the Annex VI phase 1 research is condensed in the geochemical-transport model PHREEQM-2D. This two-dimensional coupled model that was developed as a part of the research, describes the transport of heat, groundwater and solutes in the subsoil. Solute concentrations may change due to mineral equilibrium dissolution and precipitation processes and cation exchange (Willemsen, 1992).

The coupled geochemical-transport model was used during the IEA Annex VI research to simulate and extrapolate the results of the geochemical experiments and to predict the effectiveness and environmental impacts of water treatment over a longer period of time. An important other application of the coupled model is the prediction of the behaviour of pollutants in the soil and the groundwater.

2.2 Water treatment

The principal geochemical processes that can cause operational problems in ATES installations are precipitation of carbonates, precipitation of iron/manganese hydroxides and of silicates (Appelo, 1990). Furthermore, the formation of gas bubbles which may cause clogging of the infiltration wells must be taken into account. The formation of gas bubbles is however not a geochemical process but a physical process.

Silicates dissolve at higher temperatures and can precipitate upon cooling of the groundwater. Problems as a result of the precipitation of silicates have not been observed and it is expected that such problems will not arise in ATES systems if the groundwater temperature does not rise above some 100 °C.

Precipitation of carbonates is generally a result of rising groundwater temperatures. Sometimes carbonate precipitation is a result of (unintended) degassing of the groundwater. The experimental results show that carbonate precipitation is inhibited in groundwater containing organic matter or phosphates. Under such conditions a considerable over-saturation of one or more carbonates in the groundwater can occur without precipitation. This implies that water treatment will not need to be so intensive to prevent carbonate precipitation, and that at lower temperatures ATES will generally not require water treatment. In such cases storage temperatures are meant of up to a maximum of 40 to 60 °C, depending on the chemical composition of the groundwater.

Precipitation of iron/manganese hydroxide can be almost completely ascribed to:

* the entrance of air into the installation. In a good design and sound operation of the installation this can be avoided.
* the withdrawal of different, chemically incompatible water types from the same well. In this case, water treatment seems the only solution to avoid clogging due to iron/manganese precipitation.

Biomass clogging due to excessive biomass growth was not observed in all the ATES sites examined nor in the experiments performed. The availability of a nutrient carbon source is believed to be the limiting factor for bacterial survival and growth in aquifers.

2.3 Environmental impacts

As mentioned before, the environmental impacts due to heat losses and groundwater level changes are not within the scope of this research.

Significant environmental impacts as a result of temperature changes in soil and groundwater were not observed, not as a resultant of geochemical changes nor as a resultant of microbiological processes. Pathogenic bacteria have not been observed in the ATES systems examined. The contamination of a model ATES system with pathogenic bacteria (Coliform bacteria, Legionella, and pathogenic Pseudomonas) did not generate significant increases in bacterial population (Winters, 1992).

On the basis of this it may be concluded that the water treatment method to be applied is the determinant factor for the geochemical and/or microbiological environmental impacts of ATES.

3 PRINCIPAL RESULTS PHASE 2

3.1 Introduction

The second phase of the Annex VI research was aimed at the development and testing of water treatment techniques which are suitable for application in ATES systems. A number of specific boundary conditions apply to those water treatment techniques. First of all, the environmental impacts resulting from water treatment must be very small because the groundwater treated infiltrates the soil and partly spreads downstream of the store. In the second place, consideration must be taken of the interactions between the treated groundwater and the sediment: these interactions (such as cation-exchange) can to a great extent annihilate the effect of the treatment. Both boundary conditions have led to the development of water treatment techniques that are partly based on new concepts.

The experiments undertaken have demonstrated that a number of the water treatment techniques examined are suitable to prevent or control the problems caused by precipitation. In the latter case precipitation occurs under controlled conditions, so that clogging of heat exchangers, wells, etc., can be prevented. Below the successful water treatment techniques will be briefly described.

3.2 Water treatment against carbonate problems

Ion exchange appears to be an effective water treatment technique to prevent the precipitation of carbonates. This commercially available water treatment technique was tested, among others, at the St. Paul field test facility and the University of Utrecht high temperature ATES site. Ion exchange is not without negligible environmental impacts. The ion exchange alters the cation composition of the groundwater, which usually results in an increase of the sodium concentration (depending on the type of ion exchanger selected). Furthermore, a consequence of the periodical regeneration of the ion exchanger is a considerable salt dumping.

A new water treatment concept to prevent the precipitation of carbonates is CO2-treatment (Koch, 1992). The principal of this method is shown schematically in Figure 2. While the groundwater is heated the carbonate equilibrium is altered by dissolution of CO2 such that there is no precipitation in the water. If so desired, the CO2 can be removed again from the groundwater after it has been cooled.

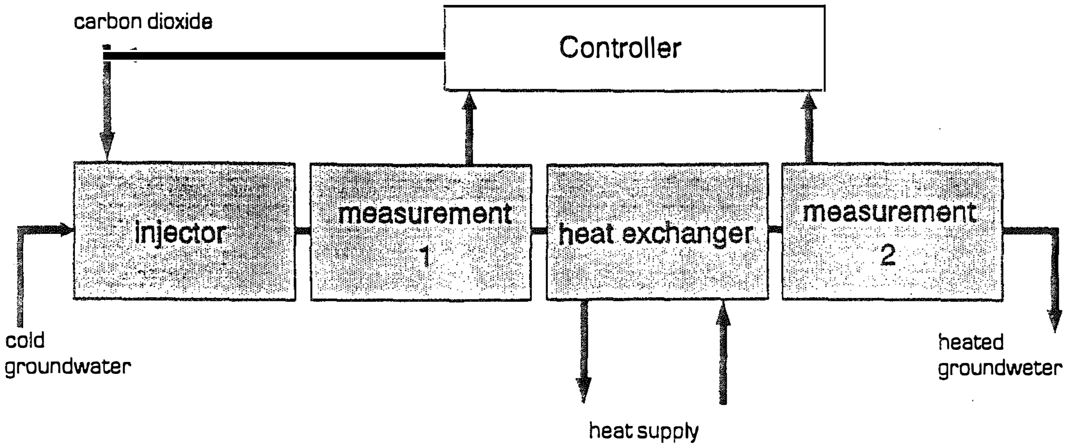

Figure 2 Schematic depiction of CO2-treatment.

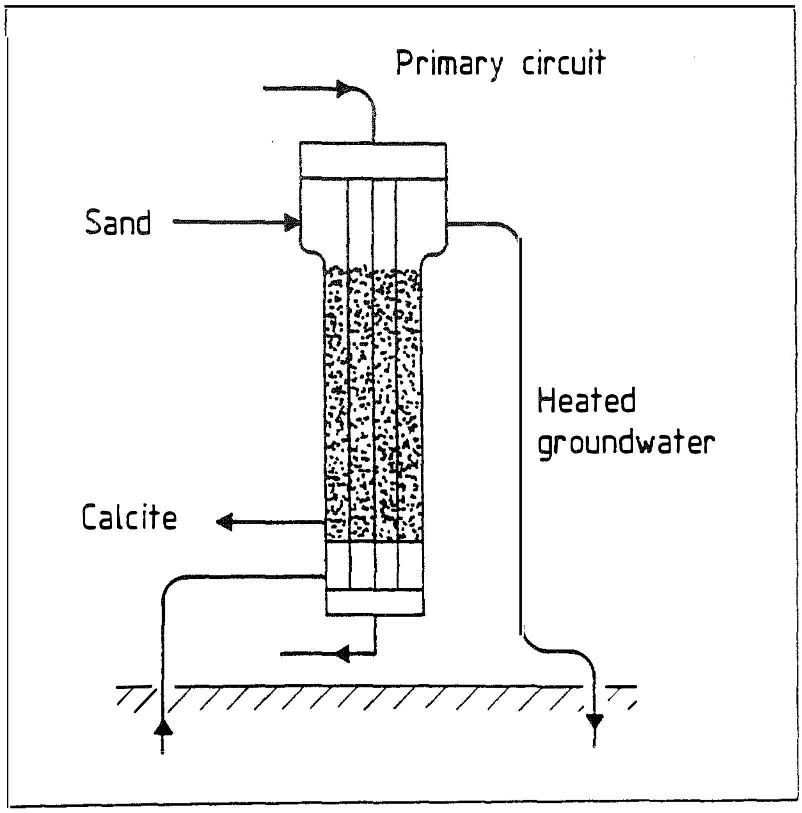

Figure 3 Schematic depiction of FBRHE.

A new water treatment concept to allow carbonate precipitation under controlled conditions is the fluidized bed reactor/heat exchanger (FBRHE). This water treatment method is shown in Figure 3. The principal is based on a combination of a fluidized bed reactor and a tube heat exchanger. The fluidized bed consists of small sand/calcite particles inside the tube heat exchanger. The precipitation of carbonates, which is result of the temperature rise of the groundwater, takes place on the fluidized bed in the reactor/heat exchanger.

3.3 Water treatment against Fe/Mn problems

In many cases the precipitation of iron/manganese hydroxide can be prevented by ensuring that no air can enter the ATES system. To this end, overpressure must be maintained in the installation both when in operation and when stationary. Iron/manganese hydroxide precipitation can, however, not be prevented when groundwaters with different redox conditions are withdrawn and mixed. In such cases water treatment will be necessary.

Underground oxidation is a water treatment technique to prevent problems caused by iron/manganese hydroxide precipitation. In this case, iron/manganese precipitation takes place in the aquifer by infiltrating groundwater with a high redox potential (for example oxygen-rich groundwater). The applicability of in-situ oxidation of iron and manganese was demonstrated at Hämeenlinna, Finland, with the help of oxygen-rich groundwater, and at Knisslinge, Sweden, with the help of nitrate-rich groundwater.

Another water treatment method to remove iron and manganese from groundwater is the use of a bioreactor. This water treatment method is based on a new concept and shown in Figure 4. In the reactor the iron and manganese are oxidized by means of a biochemical process. The reaction surface is created by floating pallets. A specific aspect is that the removal of iron and manganese is to take place before ATES operation begins, because the process in the bioreactor cannot take place at high temperatures.

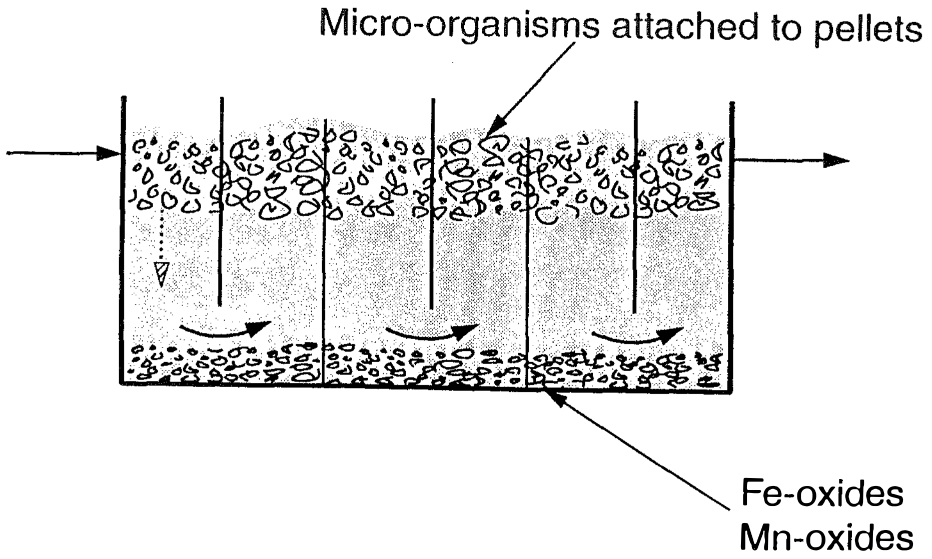

Figure 4 Schematic depiction of a bioreactor.

4. EVALUATION

The laboratory and field experiments in the field of groundwater chemistry and microbiology demonstrate that aquifer storage causes considerably less serious environmental impacts in soil and groundwater than was assumed. Significant environmental impacts as a result of geochemical and microbiological changes were not observed in either the laboratory nor the field experiments.

The observed geochemical changes can be theoretically explained. For microbiology the base for a sound theoretical explanation is still lacking so that additional observations are desirable to obtain a more extensive data base.

Furthermore, in the framework of the IEA Annex VI research, a number of new water treatment methods were developed and tested at pilot scale which meet the set goal: to prevent precipitation or allow it under controlled conditions, while serious environmental impacts are kept to a minimum in comparison to conventional water treatment methods. It should be noted that the dosage and control of some techniques require further attention when those techniques are first applied in full-scale projects. The successful water treatment methods are summarized in the table below.

Table 1: Water treatment methods applicable to ATES

PROBLEM	AVOID PROBLEM	CONTROL PROBLEM
PRECIPITATION OF CARBONATES	ION EXCHANGE CO_2 TREATMENT	FLUIDIZED BED REACTOR HEAT EXCHANGER
PRECIPITATION OF IRON/MANGANESE	PRESSURIZED, AIR TIGHT SYSTEM	IN SITU OXIDATION BIOREACTOR
DEGASSING	PRESSURIZED, AIR TIGHT SYSTEM	PARTIAL DEGASSING

For the dimensioning for ATES applications of ion exchanger, CO2-treatment, fluidized bed reactor/heat exchanger and in-situ oxidation, a software package has been developed in the framework of Annex VI (Vail, 1992).

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The Netherlands	The Netherlands Agency for Energy and the Environment (NOVEM)
Sweden	The Swedish Council for Building Research
Switzerland	l'Office Fédéral de l'Energie
United States of America	The Department of Energy

REFERENCES

Appelo, C.A.J., Griffioen, J., and van der Weiden, M.J.J. (1990). Draft Subtask B Report: (Bio)geochemical reactions. NOVEM, Utrecht.

Koch, M., and Ruck, W. (1992). Injection of CO_2 for the Inhibition of Scaling in ATES Systems. Proceedings of the 27th Intersociety Energy Conversion Engineering Conference, 4.89-4.93. SAE, Warrendale, PA, USA.

Snijders, A.L. (1991). IEA Energy Storage Programme-Annex VI: Environmental an Chemical Aspects of ATES and Research and Development of Water Treatment Methods. Proceedings of the 5th International Conference on Thermal Energy Storage, 4.13.1-4.13.7. NOVEM, Utrecht.

Vail, L.W., Jenne, E.A., and Ears, L.E. (1992). H_2O-TREAT: An Aid for Evaluating Water Treatment Requirements for Aquifer Thermal Storage. Proceedings of the 27th Intersociety Energy Conversion Engineering Conference, 4.131-4.135. SAE, Warrendale, PA, USA.

Willemsen, A. (1992). PHREEQM-2D: A Computer Model to calculate Geochemical Reactions during Transport of Groundwater; Model Description and Application to the Utrecht University ATES. Proceedings of the 27th Intersociety Energy Conversion Engineering Conference, 4.115-4.124. SAE, Warrendale, PA, USA.

Winters, A.L. (1992). Draft Subtask D Report: Summary of Research on Microbiological Processes. University of Alabama, Tuscaloosa, AL, USA.